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SALINITY

Contents

Management

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Natural and Induced Soil Salinity

The term 'salinity' refers to the presence in soil and water of electrolytic mineral solutes in concentrations that are harmful to many agricultural crops. Except along seashores, saline soils seldom occur in humid regions, thanks to the net downward percolation of fresh water though the soil profile, brought about by the excess of rainfall compared with evapotranspiration. In arid regions, on the other hand, there may be periods of no net downward percolation and hence no effective leaching, so salts can accumulate in the soil. Hence the combined effect of meager rainfall, high evaporation, the presence of salt-bearing sediments, and – in many places, particularly river valleys and other low-lying areas – the occurrence of shallow, brackish groundwater which gives rise to saline soils.

Less obvious than the appearance of naturally saline soils, but perhaps more insidious, is the inadvertent induced salination of originally productive soils, caused by human intervention. Irrigation waters generally contain appreciable quantities of salts. (For example: Even with relatively good-quality irrigation water containing no more than 0.3 kg salts m^{-3}, applying 10 000 mm water per season would add as much as 3 000 kg salts ha^{-1} per year!) Crop plants normally extract water from the soil while leaving most of the salt behind. Unless leached away (continuously or intermittently), such salts sooner or later begin to hinder crop growth. Where internal drainage is impeded, attempts to leach the soil can do more harm than good, by raising the water table, waterlogging the soil, and causing capillary rise to the surface, where evaporation infuses the topsoil with cumulative quantities of salt.

Overall salinity is generally expressed in terms of the total dissolved solutes (TDS) in milligrams per liter of solution (approximately equivalent to parts per million, ppm). Salinity may also be characterized by measuring the electrical conductivity (EC) of the solution, generally expressible in terms of decisiemens per meter (dS m^{-1}).

Quantitative criteria for diagnosing soil salinity were originally formulated by the US Salinity Laboratory at Riverside, California (in its *Handbook 60*, first issued in 1954), in terms of the EC of the soil's saturation extract (i.e., the solution extracted from a soil sample that had been presaturated with water). Those criteria are still in wide use today. Accordingly, a saline soil has been defined as having an EC of more than 4 dS m^{-1}. This value generally corresponds to approximately 40 mmol salt l^{-1}. In the case of a sodium chloride solution, this equals about 2.4 g l^{-1}.

The clay fraction in saline soils is generally well flocculated. As the salts are leached, however, the

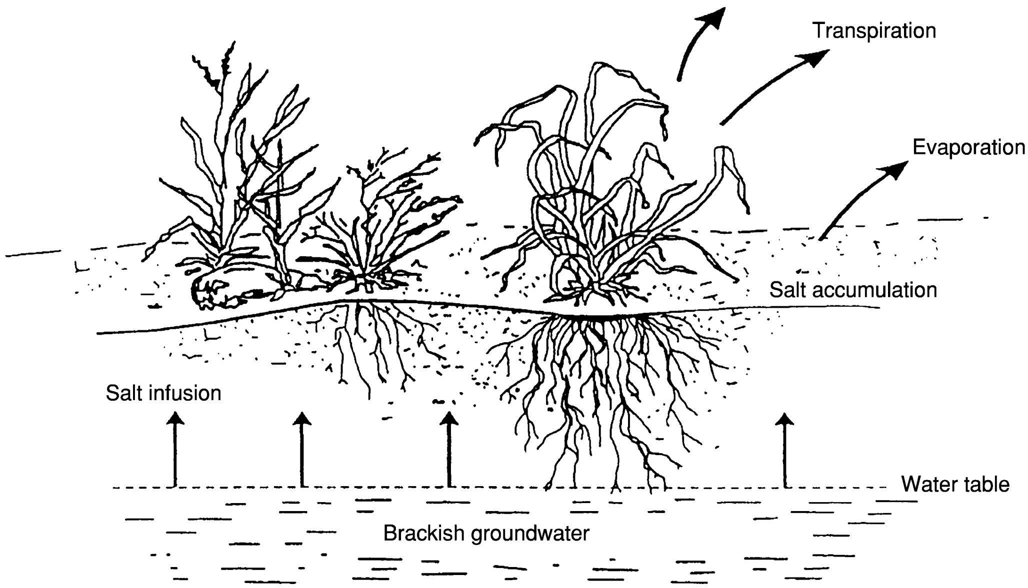

Figure 1 The process of waterlogging and salination. Reproduced with permission from Hillel D (1998) Environmental Soil Physics, Elsevier.

flocs may tend to disperse and the soil aggregates to break down (or slake). This especially occurs where an appreciable concentration of sodium is adsorbed on to the clay particles. The tendency for flocs to disperse and for aggregates to slake and collapse results in the deterioration of soil structure by the clogging of large pores in the soil, and consequently in the reduction of soil permeability. This leads to the associated phenomenon of soil sodicity, also known as alkalinity (Figure 1).

Irrigation Water Quality

Solutes can be added to the soil solution in rainfall (especially along seacoasts, where sea spray mixes with the rain) or in irrigation water infiltrated from above, in groundwater rising by capillarity from below, in the dissolution of salts initially present in solid form within the soil and subsoil, and in the artificial application of agricultural chemicals (e.g., fertilizers, pesticides, and soil amendments). Methods for removal of solutes from the soil include uptake by plants (generally of minor importance), downward transport by percolation and drainage (leaching), erosion of the soil surface by overland flow and by wind, precipitation or adsorption on to the solid phase and conversion to insoluble or unavailable forms, and – for some substances – volatilization of gaseous compounds. To avoid the accumulation of salts to toxic levels, their inputs to the soil must not exceed the rate of their removal from the soil or their conversion to unavailable forms within it. The control of soil salinity must therefore include measures to control both the inputs and the outputs of salts.

Among the various inputs of salts listed above, irrigation water often plays a major role. The quality of irrigation water may affect soil salinity and sodicity, cation exchange, soil acidity or alkalinity, nutrient availability, clay dispersion and flocculation, as well as soil structure, infiltration, and aeration. Clearly, therefore, the composition of irrigation water is an important determinant of soil productivity, crop growth, and agricultural drainage quality. The hazard posed by irrigation water containing salts of varying composition and concentration depends on soil conditions, climatic conditions, crop species and variety, and the amount and frequency of the irrigation applied. In general, irrigation water of EC less than $0.7\,\mathrm{dS\,m^{-1}}$ poses little or no danger to most crops, whereas EC values more than $3.0\,\mathrm{dS\,m^{-1}}$ may restrict the growth of most crops. The major components of salinity are the cations Ca, Mg, and Na, and the anions Cl, SO_4, and HCO_3. The potassium, nitrate, and phosphate ions, though important nutritionally, are usually minor components of soil salinity. In addition, certain constituents (such as boron) may have an important effect on crop growth even though their concentrations are usually too low to have any substantial effect on the soil's total salinity.

Irrigation waters of different sources, locations, and seasons vary greatly in quality (Table 1). Some irrigation waters contain as little as $50\,\mathrm{g\,salts\,m^{-3}}$, and others as much as $3000\,\mathrm{g\ salts\,m^{-3}}$. Since the volume of water applied in irrigation to a crop during its growing season commonly varies between 5000 and $20\,000\,\mathrm{m^{-3}\,ha^{-1}}$, the salt input to a crop may range between 250 and $60\,000\,\mathrm{kg\ ha^{-1}}$.

Table 1 Classification of water quality according to total salt concentration

Designation	*Total dissolved salts (ppm)*	*EC (dS m^{-1})*	*Category*
Fresh water	<500	<0.6	Drinking and irrigation
Slightly brackish	500–1 000	0.6–1.5	Irrigation
Brackish	1 000–2 000	1.5–3	Irrigation with caution
Moderately saline	2 000–5 000	3–8	Primary drainage
Saline	5 000–10 000	8–15	Secondary drainage and saline groundwater
Highly saline	10 000–35 000	15–45	Very saline groundwater
Brine	>35 000	>45	Seawater

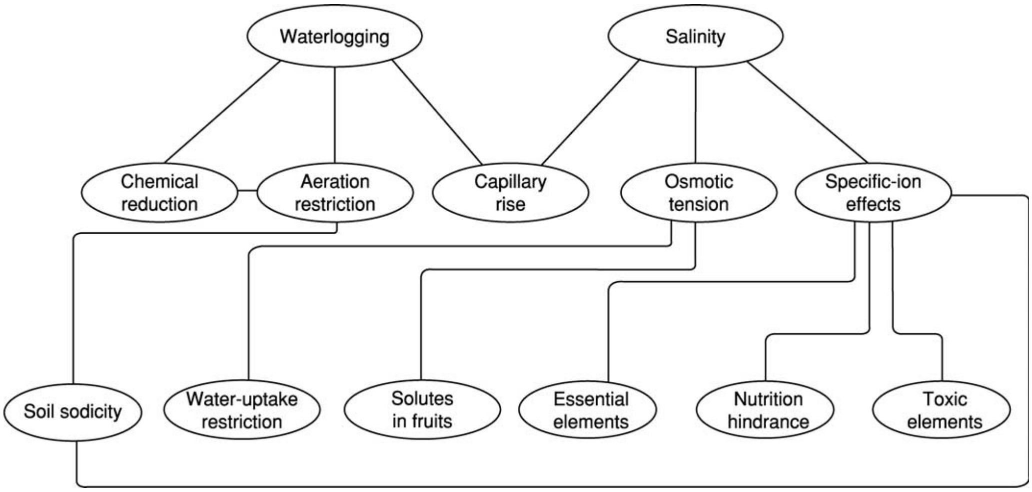

Figure 2 Effects of salinity and sodicity on plants.

Another important criterion of irrigation water quality is the sodium adsorption ratio (SAR). High alkalinity of irrigation water, manifested when the pH value is more than 8.5, generally indicates the predominant presence of sodium ions (often associated with the bicarbonate anion) and poses a danger of soil sodification. Freshly pumped groundwater may have a high SAR even if the pH is less than 8.5, owing to the presence of dissolved CO_2 (samples of such water should be aerated to allow the carbon dioxide to effervesce prior to measurement of the pH).

With high-SAR water, irrigation by sprinkling will increase the soil's tendency to form a surface seal (crust) under the impact of the drops striking the bare soil. Flood irrigation may also cause the breakdown of soil aggregates by air slaking. On the other hand, application of water by drip irrigation at spaced points on the surface or below it, may lessen the physical disruption of soil structure that would otherwise take place under the influence of high-SAR water. High-pH water may cause nutritional as well as structural problems. The addition of gypsum to the water or to the soil surface may help in both respects, by promoting the flocculation of clay and the nutritional balance of the soil solution.

In certain circumstances and with appropriate precautions, brackish water may safely be used for the irrigation of salt-tolerant crops. This includes the secondary use, or reuse, of drainage waters. Especially suitable for this purpose are deep sandy soils that are prevalent in some arid regions, where internal drainage is unrestricted and there is little risk of either groundwater rise or of soil salination and sodification.

The use of brackish water for sprinkling irrigation, however, may cause foliar injury. The degree of injury depends on the following factors: concentrations of ions in the water, sensitivity of the crop at various growth stages, water stress of the plants prior to irrigation, and frequency of irrigation. The potential damage also depends on the prevailing environmental conditions, including the temperature and relative humidity of the atmosphere, which affect the rate of evaporation. Sprinkling at night, when the atmospheric temperature and evaporativity are relatively low, can reduce foliar absorption and injury.

The greater the rate of evapotranspiration and the longer the interval between irrigations, the more concentrated the residual solution in the root zone and the more severe the salt stress imposed on the plants (Figure 2). Hence, when irrigation water is brackish, a common management strategy is to increase the frequency of irrigation so as to maintain a high content of water and to prevent the rise of salt concentration in the root zone. Thanks to its ready adaptability to high-frequency irrigation, drip irrigation beneath the canopy appears to be the most appropriate method to use with brackish water, especially as it avoids direct foliar exposure to saline water.

Brackish drainage water may also be used in a system of agroforestry. Salt-tolerant trees are capable of thriving when irrigated with brackish water, and also of lowering the water table by the extraction and transpiration of water from deeper layers in the soil, thus reducing the volume and expense of needed drainage in some areas. Among the trees suitable for this type of agroforestry and biodrainage are certain species of eucalyptus, acacia, casuarina, poplar, mesquite, and tamarisk. The harvested wood may be used for fuel, pulp, or construction.

The use of drainage wastewater entails certain distinct hazards. In some places, the concentration of nitrates may become excessive, and contribute to groundwater and surface-water contamination. Heavy metals and various other toxic materials can pose a problem. They tend to accumulate in the soil and thence enter the biological food chain. Especially hazardous are industrial waste products that may be carcinogenic as well as toxic.

Groundwater Drainage

The presence of a high water table can be either a blessing or a curse. The blessing occurs when, in periods of low rainfall or deficiency of water for irrigation, upward capillary flow from the water table augments the water supply to the roots. The curse occurs as the rising water brings up salts from below and thereby salinizes the root zone. In the field, upward capillary rise and downward percolation may take place alternately during the year. Percolation occurs typically during the rainy and early irrigation seasons, when the water requirements of the crop are relatively low and the water supply from above is high. On the other hand, upward flow takes place later in the irrigation season, when the water requirements are high and both rainfall and irrigation are restricted. Over the long term, a net downward flow of salt-bearing water through the root zone is essential to sustainable productivity.

The term ‘drainage’ can be used in a general sense to denote outflow of water from soil. More specifically, it can serve to describe the artificial removal of excess water, or the set of management practices designed to prevent the occurrence of excess water. The removal of free water tending to accumulate over the soil surface by appropriately shaping the land is termed ‘surface drainage’ and is outside the scope of this article. Finally, ‘groundwater drainage’ refers to the outflow or artificial removal of excess water from within the soil, generally lowering the water table or preventing its rise.

In waterlogged soils, gas exchange with the atmosphere is restricted to the surface zone, while, within the profile, oxygen may be almost totally absent and carbon dioxide may accumulate. Under anaerobic conditions, various substances are reduced chemically from their normally oxidized state. Toxic concentrations of ferrous, sulfide, and manganous ions can develop. These, in combination with products of the anaerobic decomposition of organic matter (e.g., methane) can greatly inhibit plant growth. At the same time, nitrification is prevented, and various plant and root diseases (especially fungal) are more prevalent. High-moisture conditions at or near the soil surface make the soil susceptible to compaction and puddling by animal and machinery traffic. Necessary operations (e.g., tillage, planting, spraying, and harvesting) are thwarted by poor trafficability (i.e., the ability of the ground to support vehicular traffic). Furthermore, the surface zone of a wet soil does not warm up readily at springtime, owing to greater thermal inertia and downward conduction, and to loss of latent heat by the higher evaporation rate. Consequently, germination and early seedling growth are retarded. All these phenomena are in addition to the tendency of waterlogged soils, especially in arid areas, to become saline.

The artificial drainage of groundwater is generally carried out by means of drains, which may be ditches, pipes, or ‘mole channels,’ into which groundwater flows as a result of the hydraulic gradients existing in the soil. The drains themselves are made to direct the water, by gravity or by pumping, to the drainage outlet, which may be a stream, a lake, an evaporation pond, or the sea. In some places, drainage water may be recycled or reused for agricultural, industrial, or residential purposes, as well as for agroforestry or the irrigation of ornamental plants. Because drainage water may contain potentially harmful concentrations of salts, fertilizer nutrients, pesticide residues, and various other toxic chemicals, as well as biological pathogens, it is not enough to provide means to ‘get rid’ of it; attention must be devoted to the quality of the water to be disposed of and to the long-term consequences of its disposal.

The disposal of salt-bearing effluent may pose a danger to rivers and to groundwater. If the drainage water is returned to a river or an aquifer serving as a water source, or if the drainage is to be reused directly,

Table 2 Prevalent depths and spacing of drainage pipes in different soil types

Soil type	*Hydraulic conductivity ($m\,day^{-1}$)*	*Spacing of drains (m)*	*Depth of drains (m)*
Clay	1.5	10–20	1–1.5
Clay loam	1.5–5	15–25	1–1.5
Loam	5–20	20–35	1–1.5
Fine, sandy loam	20–65	30–40	1–1.5
Sandy loam	65–125	30–70	1–2
Peat	125–250	30–100	1–2

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its load of corrosive salts and other pollutants may affect downstream agriculture, households, water utilities, and industry. Where persistent pesticides are applied to irrigated land, their residues can cause further damage to biotic communities in riverine, estuarine, and lacustrine habitats, as well as to public health. Construction of evaporation ponds for disposal of drainage water generally requires the allocation of approximately 10% of the land area. Care must also be taken to avoid leaks and consequent salination of the underlying groundwater. The loss of potentially valuable land, the costs of construction and conveyance, and the environmental impacts may make such ponds impractical in some cases.

Various equations, empirically or theoretically based, have been proposed for determining the desirable depths and spacings of drain pipes or ditches in different soil and groundwater conditions. In the Netherlands, the country with the most experience in drainage, common criteria for drainage are to provide for the removal of approximately 7 mm per day, and to prevent a water table from rising above a depth of 0.5 m from the soil surface. In more arid regions, because of the greater evaporation rate and groundwater salinity, the water table must generally be kept much deeper. In the Imperial Valley of California, for instance, the drain depth ranges from approximately 1.5 to 3 m, and the desired water table depth midway between drains is at least 1.2 m. For medium- and fine-textured soils, the depth should be even greater where the salinity risk is high. Since there is a practical limit to the depth of drain placement, it is the density of drain spacing that must be increased under such circumstances (Table 2).

Leaching Processes

To prevent salts from accumulating in the root zone during repeated cycles of irrigation and evapotranspiration, the obvious remedy is to apply water in an amount greater than evapotranspiration, so as deliberately to cause a fraction of the applied water to flow through the root zone and flush away the excess salts. However, unless the water table is very deep or lateral groundwater drainage is sufficiently rapid, the extra irrigation can cause a progressive rise of the water table. Therefore, the amount of water applied must be optimized to allow leaching without water-table rise. The concept of 'leaching requirement' was first developed by the US Salinity Laboratory in Riverside, California. It has been defined as the fraction of the irrigation water that must be percolated out of the bottom of the root zone in order to prevent average soil salinity from rising above some specifiable level.

According to the standards developed there, the maximum concentration of the soil solution in the root zone, expressed in terms of EC, should be kept below $4\,dS\,m^{-1}$ for sensitive crops. Salt-tolerant crops such as beets, alfalfa, and cotton may give satisfactory yields at values up to $8\,dS\,m^{-1}$. The problem encountered in any attempt to apply such a simplistic criterion is that in the field (unlike the case of plants grown in solution culture or in small containers) the concentration of the soil solution varies greatly in space and time. In addition, the sensitivity of any crop to salinity depends on its stage of growth and on such variables as ambient temperature, atmospheric humidity, soil matric suction, and nutrient availability.

The leaching requirement depends on the salt concentration and composition of the irrigation water, on the amount of water extracted from the soil by the crop, and on the salt tolerance of the crop, which determines the maximum allowable concentration of the soil solution in the root zone. Assuming steady-state conditions of throughflow (thus disregarding short-term fluctuations in soil-moisture content, flux, and salinity), and furthermore assuming no appreciable dissolution or precipitation of salts in the soil and no significant removal of salts by the crop or capillary rise of salt-bearing water from below, the following simple equation is obtained:

$$V_d/V_i = c_i/c_d \qquad [1]$$

in which V_d and V_i are the volumes of drainage and of irrigation, respectively, and c_d and c_i are the corresponding concentrations of salt. Water volumes are normally expressed per unit area of land as equivalent depths of water, and salt concentrations are generally measured and reported in terms of EC. Because the volume of water drained is the difference between the volumes of irrigation and evapotranspiration (i.e., $V_d = V_i - V_{et}$), we can transform the last equation as follows:

$$V_i = [c_d/(c_d - c_i)]V_{et} \quad [2]$$

This is equivalent to the formulation given in the US Salinity Laboratory's Department of Agriculture (USDA) Handbook No. 60:

$$d_i = [E_d/(E_d - E_i)]/d_{et} \quad [3]$$

where d_i is the depth of irrigation, d_{et} the equivalent depth of 'consumptive use' by the crop (evapotranspiration), and E_d and E_i are the electrical conductivities of the drainage and irrigation waters, respectively.

The leaching requirement equation implies that, by varying the fraction of applied water percolated through the root zone, it is possible to control the concentration of salt in the drainage water and hence to maintain the concentration of the soil solution in the main part of the root zone at some intermediate level between c_i and c_d. However, the leaching requirement concept disregards the distribution of salts within the root zone itself, as it is affected by the frequency and spatial variability of irrigation, as well as by its quantity and water quality. In particular, the variation of root-zone salinity is affected by the pattern and degree of soil moisture depletion between irrigations. The less frequent the irrigation regime, the greater the buildup of salt between successive irrigations. In some cases, the commonly recommended leaching fraction may not be sufficient to prevent the reduction of yield below its potential, especially if the climatically imposed evaporation rate is high and the irrigation water is brackish.

With modern methods of high-frequency irrigation, it is possible to maintain the soil solution in the surface zone at a concentration nearly equal to that of the irrigation water. This zone can be deepened by increasing the volume of water applied. Beyond this zone, the salt concentration of the soil solution increases with depth to a salinity level depending on the leaching fraction. High-frequency irrigation not only lowers the concentration of the soil solution in the upper zone (where most roots proliferate), but also tends to minimize the matric suction of soil moisture.

Extensive research has shown that leaching soils at a water content below saturation (e.g., under low-intensity sprinkling or intermittent ponding) can produce more efficient leaching that can be achieved by the once-standard method of continuous flooding. In a soil with macropores – cracks, wormholes, or decayed root channels – much of the water under ponding moves rapidly down those large passageways, bypassing the greater volume of the soil containing the salt, so it is largely ineffective in leaching the micropores of the soil matrix. In contrast, under low-intensity sprinkling, the soil never becomes saturated, so a greater portion of the applied water moves through the soil matrix, thus producing more efficient leaching per unit volume of water infiltrated. However, the processes of infiltration and unsaturated flow under low-intensity sprinkling are inherently slower and require more time than saturated infiltration under ponding.

Nonuniformity of irrigation as well as of soil is a complicating factor. If the leaching requirement is not met throughout the field, soil salinity will prevail in spots, wherever leaching is insufficient. Whether to apply copious amounts of water to the entire field so as to ensure that the leaching requirement is met everywhere, or to accept some reduction in yield in parts of the field, must be determined from an economic analysis of costs and benefits. Such an analysis should take into consideration the danger that saline spots might recur (and perhaps even grow in extent and severity) from year to year. One answer is to apply extra water preferentially to the spots that need it most, but such a strategy requires a flexible irrigation system that would allow controlled variability of water delivery. Although such a specialized irrigation system is likely to be expensive to install and operate, it may well be worthwhile in the long run.

Soil Amendments

The leaching process is enhanced if the applied water contains a sufficient concentration of electrolytes to reduce swelling and dispersion of clay in the soil. Where leaching occurs with water of very low salinity (e.g., rainwater), soil permeability can be increased by the surface application of a slowly soluble electrolytic salt – preferably a substance containing a divalent cation such as calcium, to prevent the sodium ion from dispersing the clay. Such materials, commonly known as soil amendments, can replace exchangeable sodium with flocculation-promoting divalent ions.

The most commonly considered soil amendment for the purpose of improving the structure and the permeability of soils, especially those prone to becoming sodic, are dihydrate calcium sulfate (gypsum) and dihydrate calcium chloride. Gypsum is generally the preferred soil amendment, thanks to its ready availability in many places and to its relatively low cost. It may be derived from mining or be available as a by-product of the phosphate-fertilizer industry. The solubility of pure gypsum is approximately 2.15–2.63 $kg\,m^{-3}$, depending somewhat on temperature. Applied gypsum dissolves in the soil solution until its solubility limit is reached or until its supply is exhausted. The rate of dissolution of applied gypsum depends on its source and degree of granulation. Industrial gypsum generally dissolves more rapidly than mined gypsum, which generally contains impurities. The amount of gypsum needed to replace the exchangeable sodium depends on the initial exchangeable sodium percentage, the soil's total cation exchange capacity, its bulk density, and the depth of the soil to be treated effectively. If elemental sulfur is added to a sodic soil in lieu of gypsum, it must be oxidized *in situ* to become effective. Upon oxidation, it forms sulfuric acid, which then reacts with lime in the soil to produce gypsum.

Early-Warning Systems

In many cases, irrigation systems are organized and irrigation is begun long before drainage is installed. Indeed, an irrigation project can often function unimpeded for years, even decades, without artificial drainage. In some cases, the land is so well drained naturally that irrigation can thus be continued for a very long time. However, far more typically, the processes of groundwater rise and salt accumulation proceed inexorably, so that sooner or later (especially in ill-drained river valleys, where most irrigation development takes place) the provision of artificial drainage becomes essential.

Granted that a drainage system must be planned in advance at the very outset of an irrigation project, the crucial question is when to begin installing and operating it. If installed too early, the drainage system may lie unused for some time and therefore be both unnecessary and uneconomical, and it may deteriorate in the interim before it comes into use. On the other hand, if installed after waterlogging and salination have advanced, it may be too late to restore productivity economically. These considerations emphasize the importance of having an early-warning system to indicate, before the problem becomes acute, that soil salination is incipient and that the need for drainage is imminent. Soil salinity is normally monitored by a combination of soil sampling, soil-solution sampling by vacuum extraction, and *in situ* salt sensors. Mobile devices with combined electromagnetic induction and four-electrode soil conductivity sensing systems are now under development for monitoring and mapping the distribution of soil salinity over an entire field, but such instruments have not yet entered into general use.

The detection and diagnosis of salinity are difficult in the early stages of its occurrence. Visual inspection of the soil surface may be misleading. For example, the white precipitate formed on the surface of furrow-irrigated or drip-irrigated soil may be due to relatively harmless calcite or gypsum. Visual inspection of crops provides obvious clues to salt stress only after the condition is well advanced. Crop plants suffering salt stress eventually exhibit stunted growth, smaller leaves than normal, and discoloration. Such symptoms first occur in spots, rather than uniformly over the field. Since factors other than salinity (e.g., water stress, nutrient deficiencies, or misapplied pesticides) may produce similar symptoms, visually observed indications of apparent salinity should be checked by chemical analyses of soil, plant, and water samples. One good way to detect the early appearance of salinity is to place plants that are known to be particularly salt-sensitive at regularly spaced intervals throughout the irrigated area. Such interspersed detector plants may reveal early symptoms of physiological stress and thus provide a timely warning of problems that are likely to be exacerbated over time.

An important indicator of the salinity hazard is the depth of the water table. There is cause for concern whenever it approaches within 1.5–2 m of the soil surface. Hence the water table should be monitored regularly by means of observation wells and piezometers (Figures 3 and 4). Both are vertical tubes that

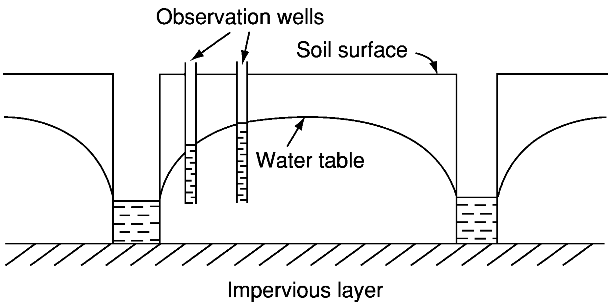

Figure 3 Observation wells to determine elevation of the water table. Reproduced with permission from Hillel D (1998) Environmental Soil Physics, Elsevier.

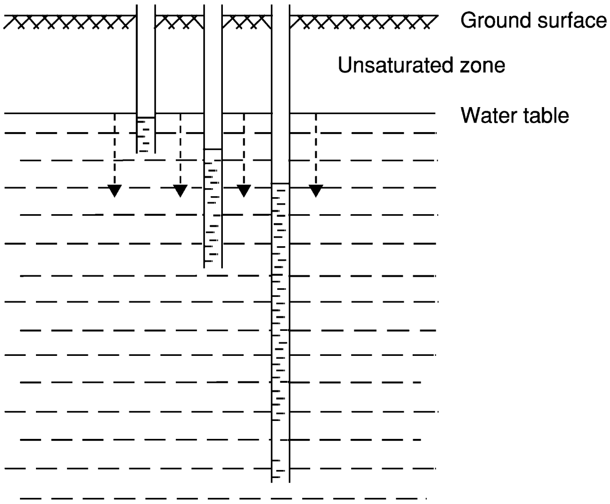

Figure 4 Piezometers to determine vertical pressure gradients below the water table. Reproduced with permission from Hillel D (1998) Environmental Soil Physics, Elsevier.

are inserted into the soil to a depth far below the water table. The difference is that an observation well is perforated to permit free inflow of groundwater along the length of the tube below the water table; in contrast, a piezometer's only opening is at the bottom. Hence a piezometer indicates the hydraulic head (pressure) of the water at the bottom of the tube, rather than the position of the water table. Several piezometers, inserted side by side to different depths, can indicate the vertical gradient of the hydraulic head below the water table. The direction and magnitude of that gradient are indicative of the tendency of the groundwater to rise or fall.

See also: **Solute Transport**

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Physical Effects

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Introduction

Environmental control and agricultural management problems involve the simultaneous transport of water and mixed salts solutions with ions that interact with the soil matrix. The soil solution–soil matrix interactions include phenomena such as cation exchange, anion exclusion, precipitation and dissolution, swelling and reorganization of the soil colloid structures, and, concurrently, rearrangement of the soil pore-size distribution; the latter can affect the soil hydraulic conductivity and retentivity. These interactions, therefore, may considerably affect water flow and solute transport.

The magnitude of the soil solution–soil matrix interactions depends to a large extent upon the types and amounts of inorganic and organic soil colloids. Among soil mineral colloids, the most reactive constituents are the smectite minerals (e.g., montmorillonite, beidellite, monronite), characterized by dioctahedral structure. The presence of these minerals imparts a considerable cation exchange capacity and/or specific surface area to soils from arid and semiarid regions. Furthermore, the smectite minerals are capable of considerable expansion at moderate-to-high exchangeable sodium levels in the presence of relatively low salt soil-solution concentration. Hence, they can impart rather substantial salinity-dependent water retention and conductivity changes to soils, and, concurrently, may considerably affect water flow and solute transport.

Here the emphasis is on the effect of salinity on soil physical properties relevant to water flow and solute transport, in particular, soil water retentivity and conductivity.

Water Retention and Swelling in Salt-Affected Soils

The amount of water retained by the soil depends largely upon the mineral and organic colloid contents of the soil, although the structural arrangement of soil